ICES CM 2212/I:04

Spatial and temporal variation of anchovy predation by albacore and bluefin tuna in the Bay of Biscay

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Abstract

The recent collapse and recovery of the anchovy population in the Bay of Biscay raised the need to assess environmental influences on the mortality of juvenile stages, in particular the impacts of predation by tunas. Stomachs of 1354 albacore and 579 bluefin tunas were collected in several zones of the Bay of Biscay and adjacent waters in the summers of 2004–2007 (period of depletion in anchovy population) and of 2009–2010 (period of recovery). Among different years, average daily consumption of anchovy (when present in diet) varied between 6.7 and 26.5 individuals (max. 118) per day and predator for bluefin tunas, and between 4.8 and 15.5 (max. 103) for albacore. Anchovy consumption by tunas appeared to have an important interannual, seasonal, and geographical variability. Juvenile anchovy were absent from both albacore and bluefin tuna diets until early August in all years. They were also absent from albacore diet outside the inner Bay of Biscay (core area of anchovy) in 2004–2007, whereas they were present up to the most northwestern part of the Bay in 2010, which supposes a higher exposure to predation in the period of recovery. On the other hand, the absence of albacore in the inner Bay of Biscay since 2008 tends to reduce predation impacts. Anchovy appears to be a significantly more important prey for bluefin tuna than for albacore, particularly in the case of age-1 bluefin tunas. No significant relationship was found between tuna size and anchovy consumption.

Keywords: albacore, anchovy, Bay of Biscay, bluefin tuna, predation.

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1. Introduction

In the North Atlantic, juvenile (age-0 to age-4 individuals) albacore make a feeding migration between subtropical and temperate regions (Bard 1981; Santiago 2004) in summer months, when they show highest growth rates (Santiago and Arrizabalaga 2005). Some adult individuals also appear in temperate regions in late summer and autumn. Juvenile bluefin tuna also undertake feeding migrations to the Bay of Biscay in summer months (Fromentin and Powers 2005), when they also show highest growth rates (Cort, 1990).

Tunas have high standard metabolic rates compared to strictly poikilothermic fish species (Korsmeyer and Dewar 2001). This metabolic rate may be particularly high for populations that perform long-distance seasonal migrations (such as albacore and bluefin tunas in the North Atlantic), and for juvenile individuals, i.e. in rapid growth phase with possible variations or shifts in their physiology (Goñi and Arrizabalaga 2010). Therefore, their feeding ecology has critical implications for life history features of growth and survival.

In the Bay of Biscay, anchovy has one of the highest caloric content among tuna prey species, and is actually one of their most important prey (Logan et al. 2010, Goñi et al. 2011). Moreover, albacore displays a preference for anchovy when present in its feeding areas (Goñi et al. 2011), and its spatial distribution appears to be related to the presence of anchovy (Lezama-Ochoa et al., 2010). This is also the case for bluefin, its selectivity towards anchovy being higher than in the case of albacore (Goñi, 2008).

Anchovy is also one of the main forage fish of the Bay of Biscay. Being an r-selected species with a short life-span and early maturity, mortality of age-0 individuals is a key parameter of its population dynamics, as it has a direct influence on spawning biomass, which is composed of around 70-80% of age-1 individuals in years of average recruitment (Irigoien et al. 2007).

During anchovy life-cycle, juveniles (age-0) are usually present outside the shelf areas from August onwards (*ibid.*), where they can constitute a prey for albacore and bluefin tuna.

The recent collapse (2004-2008) and recovery (since 2009) of anchovy population in the Bay of Biscay raised the need to assess the environmental influences on the mortality of juvenile stages, in particular the impacts of predation by both tunas species.

2. Materials and Method

2.1. Stomachs sampled

Stomachs were sampled from 1354 albacore and 579 bluefin tunas caught in the Bay of Biscay and surrounding waters (tables 1–3). Albacore from the Northeast Atlantic were sampled from five geographic zones (fig. 1) in 2004 to 2007 (period of depletion in anchovy population), and from twelve geographic zones in 2010 (fig. 2). The 2010 sampling was done within the framework of FACTS. Albacore stomachs were collected from trolling and pelagic trawling fisheries during both periods, from recreative rod-and-reel fishery in 2004-2007 and from baiboat fishery in 2010. Size-range of albacore was 39.6 – 112.0 cm fork-length (FL).

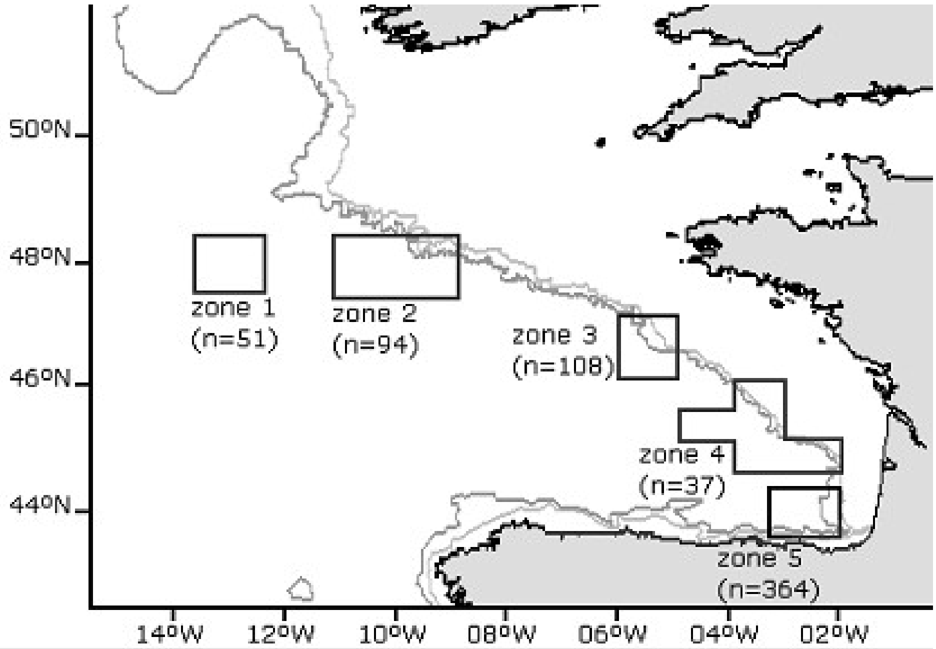


Figure 1: Locations and corresponding sample sizes of the five albacore sampling zones in the Bay of Biscay and surrounding waters for the years 2004-2007.

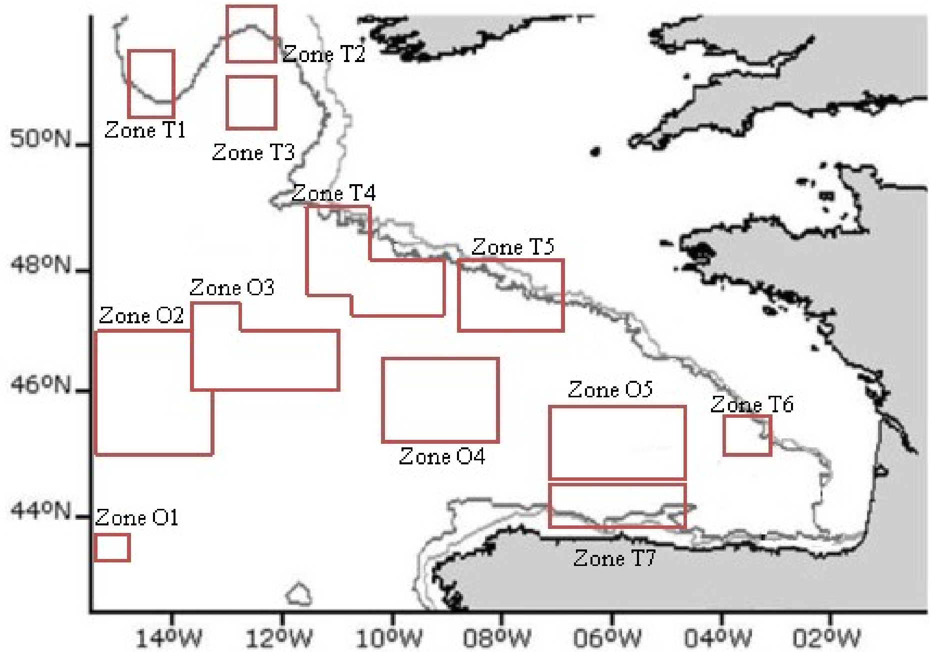


Figure 2: Locations of the twelve albacore sampling zones in the Bay of Biscay and surrounding waters for 2010. See table 2 for the corresponding sample sizes.

Table 1: Area (see fig. 1), catch period, catch time, catch depth, gear type (active vs baited) and number by age-group of 654 albacore sampled in the Bay of Biscay in 2004–2007

Area	Catch period	Catch time	Catch depth	Gear type	Total by subset
Zone 1	29/07/05 - 02/08/05	Day	surface	baited	51
Zone 2	24/08/04 - 04/10/04	Night	0-100 m	active	27
	27/07/05 - 28/07/05	Day	surface	baited	18
	28/07/06 - 30/07/06	Day	surface	baited	49
Zone 3	07/08/05 - 15/08/05	Night	0-100 m	active	66
	27/09/05 - 09/10/06				42
Zone 4	18/07/06 - 19/09/06	Night	0-100 m	active	37
Zone 5	15/06/05 - 24/10/05	Day	surface	baited	259
	10/08/06 - 31/10/06				68
	04/08/07 - 22/10/07				37

Table 2: Area (see fig. 2), catch period, catch time, catch depth, gear type (active vs baited) and number by age-group of 568 albacore sampled in the Bay of Biscay in 2010

Area	Catch period	Catch time	Catch deph	Gear type	total by subset
Zone O1	18/06/10	Day	Surface	Baited	30
Zone O2	02/07/10-09/07/10	Day	Surface	Baited	75
Zone O3	12/07/10-26/07/10	Day	Surface	Baited	157
Zone O4	19/08/10-23/08/10	Day	Surface	Baited	20
Zone O5	9/08/10-11/08/10	Day	Surface	Baited	12
	19/08/10-24/08/10	Day	Surface	Baited	16
	24/09/10-30/09/10	Day	Surface	Baited	13
Zones T1 and T4	19/08/10-27/08/10	Night	0-100m	Active	50
Zones T1 to T4	13/09/10	Night	0-100m	Active	20
	27/09/10	Night	0-100m	Active	50
Zones T1 and T5	24/09/10-27/09/10	Day	Surface	Baited	19
Zone T5 and T6	08/10/10-12/10/10	Night	0-100m	Active	50
Zone T7	01/10/10-08/10/10	Day	Surface	Baited	34
	18/10/10-25/10/10	Day	Surface	Baited	22

Juvenile bluefin were sampled only in the inner Bay of Biscay (i.e. south from 45°N and East from 05°W, see fig.1 and fig. 2), where they usually occur and are caught in summer months. They were sampled in 2004-2006 and in 2009-2010, this last sampling being done within the framework of the FACTS project (www.facts-project.eu). Bluefin stomachs were collected from baitboat and recreative rod-and-reel fisheries in 2005-2006 and from baitboat fishery in 2009 and 2010. Size-range of bluefin tuna was 58.5 – 170.0 cm FL

Table 3: bluefin tuna stomachs sampled in 2004-2006 and 2009-2010 in the Bay of Biscay

Catch period	Catch time	Catch deph	Gear type	total by subset	
				Age 1	Age 2+
28/06/04-15/07/04	Day	Surface	Baited	-	32
04/07/05-16/07/05	Day	Surface	Baited	17	2
25/07/05-29/08/05	Day	Surface	Baited	20	-
20/09/06-22/10/06	Day	Surface	Baited	3	-
06/07/09-10/07/09	Day	Surface	Baited	-	40
22/07/09-31/07/09	Day	Surface	Baited	-	77
02/08/09-14-08/09	Day	Surface	Baited	-	56
17/08/09-25/08-09	Day	Surface	Baited	-	71
19/10/09	Day	Surface	Baited	10	-
25/06/10-28/06/10	Day	Surface	Baited	-	9
6/07/10-15/07/10	Day	Surface	Baited	-	6
2/08/10-12/08/10	Day	Surface	Baited	-	42
19/08/10-30/08/10	Day	Surface	Baited	-	44
3/09/10-15/09/10	Day	Surface	Baited	-	27
16/09/10-24/09/10	Day	Surface	Baited	-	22
25/09/10	Day	Surface	Baited	98	-
4/10/10-13/10/10	Day	Surface	Baited	-	20

The fork-length of all tunas was measured, and individuals sampled after landing were weighed. In the case of individuals sampled on board, an estimated mass was calculated using the length-mass relationship by Santiago (1993) for albacore and by Cort (1990) for bluefin tuna. Individual catch dates are known for tunas caught in zone 1, zone 2 and zone 5 (Fig. 1) in 2005 and 2006, and for albacore caught in zone O1 (fig. 3) in 2010. Tunas caught by trolling, pelagic trawling, and baitboat were commercial fish. They were kept on ice on board, and generally landed 1 to 6 days after catch. Their stomachs were sampled after landing and kept frozen. Tunas caught by rod-and-reel were sampled during scientific surveys (Goñi et al. 2009) and by collaborating recreative fishermen. Their stomachs were sampled onboard immediately after catch, and frozen.

2.2. Stomach content analyses

Whole stomachs were weighed before content analysis. All contents were then removed, and the stomach lining was weighed after being rinsed and blotted dry. The difference between both masses was considered the total content mass, including gastric liquid, which often contained remains of crustaceans and fish in the most advanced digestion state. Stomach fullness was defined for each sampled tuna as the ratio between the mass of the stomach content (g) and the mass – measured or calculated – of the individuals (kg).

Each prey item was identified to the lowest possible taxon. Fishes were identified using the identification keys – based on morphological characteristics – by Ibañez Artica et al. (1989), and the online database www.fishbase.org (Froese and Pauly, 2010). Crustaceans were identified using the manual by Todd et al. (1996), which comprises morphological descriptions of crustacean species. Cephalopods were identified by the morphological characteristics of their beaks, according to the handbook by Clarke (1986). For all stomachs, the mass, number of individuals, length and digestion state of each identified prey item were recorded. The digestion state of each prey item was considered, following the four states defined in the case of albacore by Aloncle and Delaporte (1974) for crustaceans and fish prey, and the six states defined by Bertrand (1999) for cephalopod prey. No digestion state was recorded for salps and gelatinous plankton.

In 57% of the stomachs containing euphausiids, several individuals were not countable and lacked measurable parts (e.g., telson) due to partial digestion. Fresh mass could not be estimated for these individuals so reconstituted prey mass was not taken into account in this study.

Species for which only hard parts (otoliths, bones, cephalopod beaks) were found were not considered for qualitative analysis, as they are likely to be remains of prey ingested several days earlier, but their mass was taken into account for calculating stomach fullness. In the case of tunas sampled from the baitboat fishery, bait (horse mackerel (*Trachurus trachurus*) and Atlantic mackerel (*Scomber scombrus*)) was not considered in any analysis and its mass was subtracted from stomach content mass. The mass percentage of a given prey in a stomach was defined as the mass of the prey divided by the total mass of all identified prey. The mean mass percentage (MW%) of a given prey in a subset was defined as the average of its mass percentages in the stomachs of albacore caught in a particular area and period. The frequency (F%) of a given prey in a subset was defined as the percentage of predators that contained this prey in this subset.

Bluefin tuna being caught only in the inner Bay of Biscay, no geographic variation was described for this predator.

3. Results

3.1. Anchovy collapse period (2004-2007)

During this period, anchovy was present in albacore diet only in zone 5, and absent from the four other zones. In terms of number of individuals by stomach, when anchovy was present in diet we observed a mean value of 9.3 individuals per day and predator in 2005 (maximum 36 individuals), similar values in 2006 (mean 10 individuals, max. 30), but lower in 2007 (mean 4.2 individuals, max. 7). In terms of occurrence, 2005 is opposed to both 2006 and 2007, with anchovy present in 21.8% of stomachs vs 11.9% and 12.5% respectively. This opposition is also observed in the seasonal patterns, with anchovy being the predominant prey in the late summer of 2005, whereas it is marginal in the late summer of 2006 and 2007, the main prey of albacore being then blue whiting in zone 5 (fig. 3)

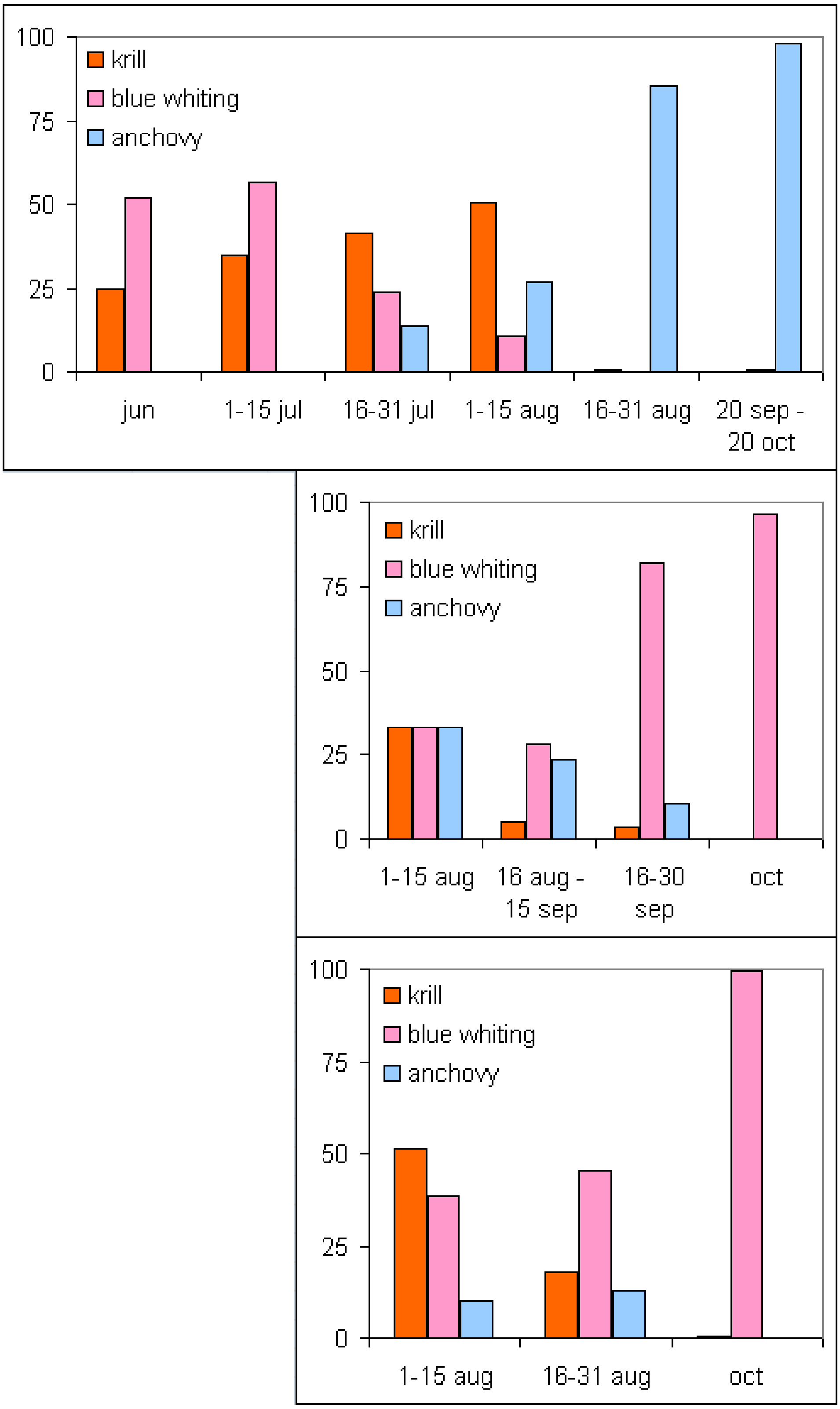


Figure 3: relative mean weight percentage of krill, blue whiting and anchovy in the diet of albacore present in zone 5 (fig.1) by period of 15 days or in summers 2005 (upper panel), 2006 (mid-panel) and 2007 (lower panel)

As for bluefin tuna, anchovy importance in its diet in the Bay of Biscay also displays an interannual and seasonal variability, as reported in Logan et al. (2010). During, the stratification of our samples did not allow us to show this variability for the years 2004-

2007. However we could compare, in terms of anchovy contribution to their diet, bluefin tuna and albacore caught in a same zone and month. Bluefin tuna actually displays a significantly higher preference for anchovy (fig. 4).

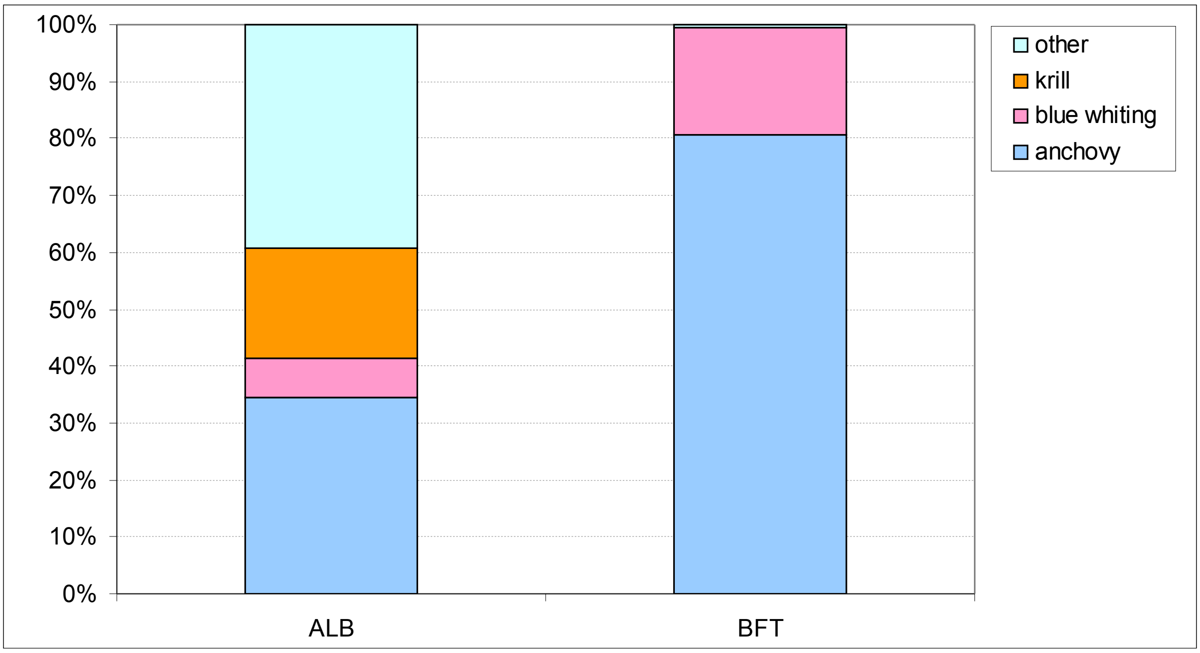


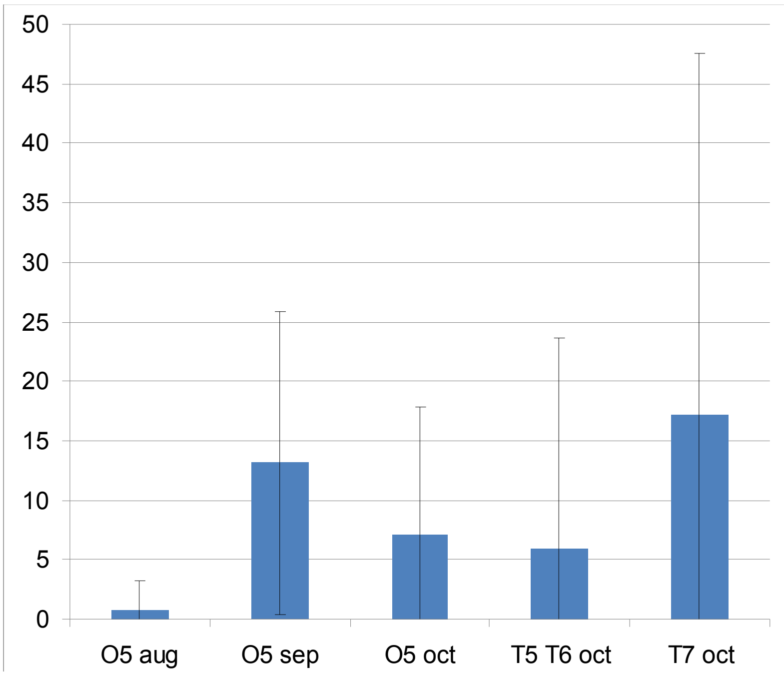
Figure 4: Proportions of anchovy, blue whiting and krill in the diet of albacore and of age-1 bluefin tuna in August 2005 in zone 5 (see fig.1) of the Bay of Biscay

3.2. Anchovy recovery period (since 2009)

In 2010 spatial distribution of anchovy was broader, as reflected by its presence in albacore stomachs in the zones T5, T6, O5 and T7 (fig. 2).

Anchovy contribution to albacore diet was also variable geographically and seasonally, with a higher number of anchovy consumed in southern areas in September and October (fig. 5).

Figure 5: mean number (and standard deviation) of anchovy consumed by day by albacore tuna caught in the Bay of Biscay in 2010 in the zones and months in which anchovy was present in albacore diet. See fig.2 for the locations of zones O5, T5, T6, T7.



In terms of weight percentage, we observe a similar pattern (fig. 6)

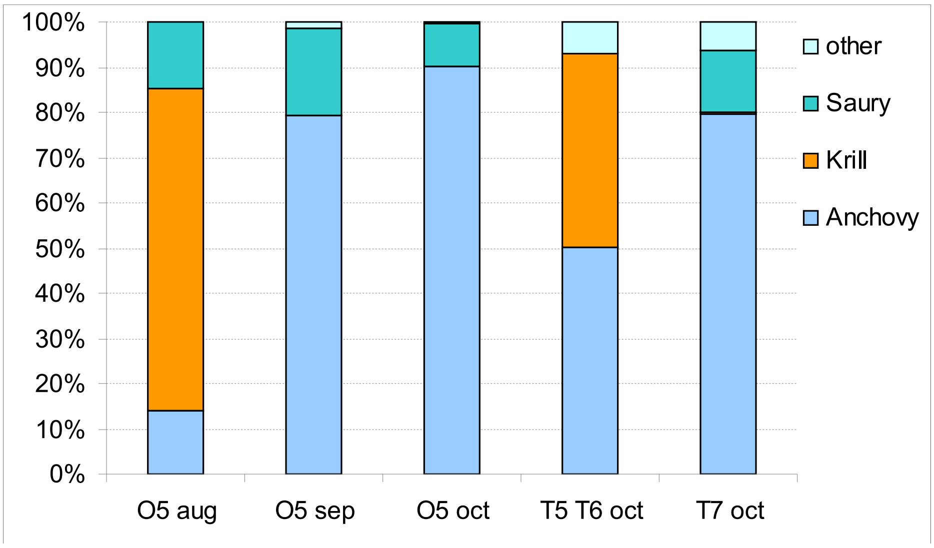


Figure 6 : relative mean weight percentage of anchovy, krill and saury in the diet of albacore present in the Bay of Biscay in 2010 in the zones and months in which anchovy was present in albacore diet. See fig.2 for the locations of zones O5, T5, T6, T7.

In the case of bluefin tuna, we also observed a seasonal and interannual variability in its anchovy consumption and in anchovy contribution to its diet.

In 2009, anchovy appeared in bluefin stomachs in late July, but its contribution to bluefin diet was significant only in late August and onwards. We note an important difference in anchovy predation between late August and October. The individuals caught in October 2009 being age-1 bluefin tunas, this difference may be due to their size.

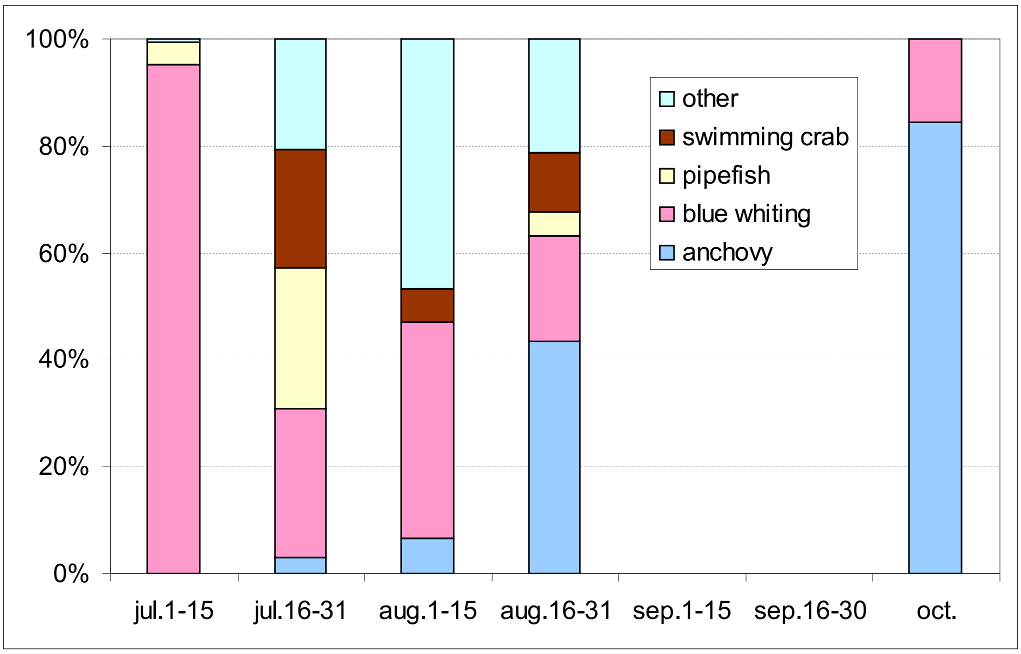


Figure 7: relative mean weight percentage of anchovy, blue whiting, pipefish and Henslow's swimming crab in the diet of bluefin present in the Bay of Biscay in 2009

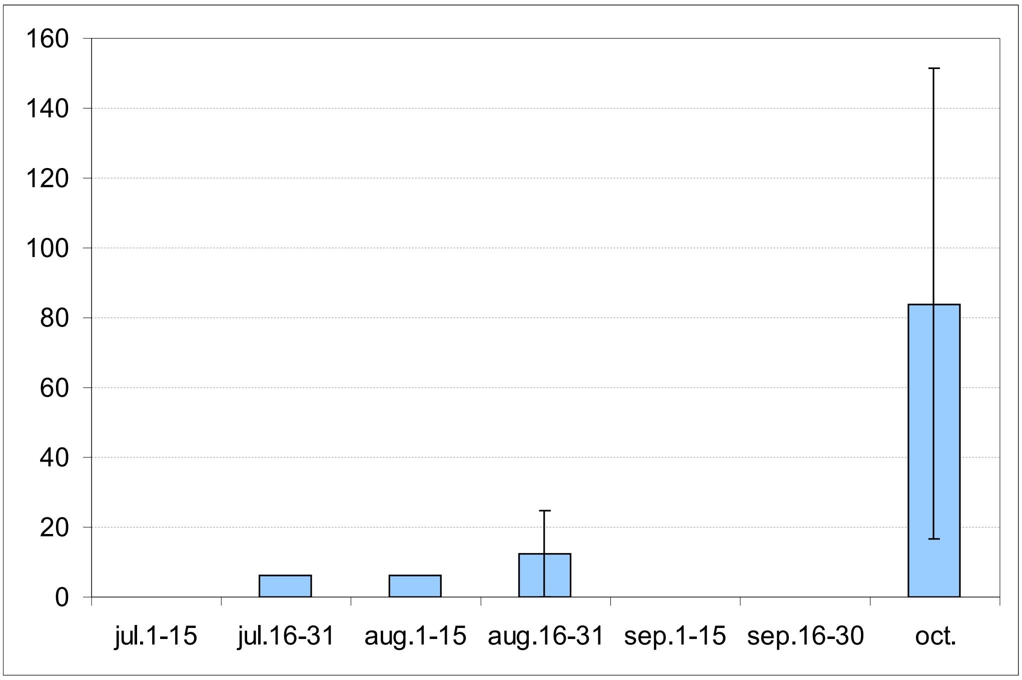


Figure 8: mean number (and standard deviation) of anchovy consumed by day by bluefin tuna caught in the Bay of Biscay in 2009.

In 2010, anchovy appears earlier in bluefin diet, and its relative importance is higher (fig. 9), as well as its number by stomachs (fig.10)

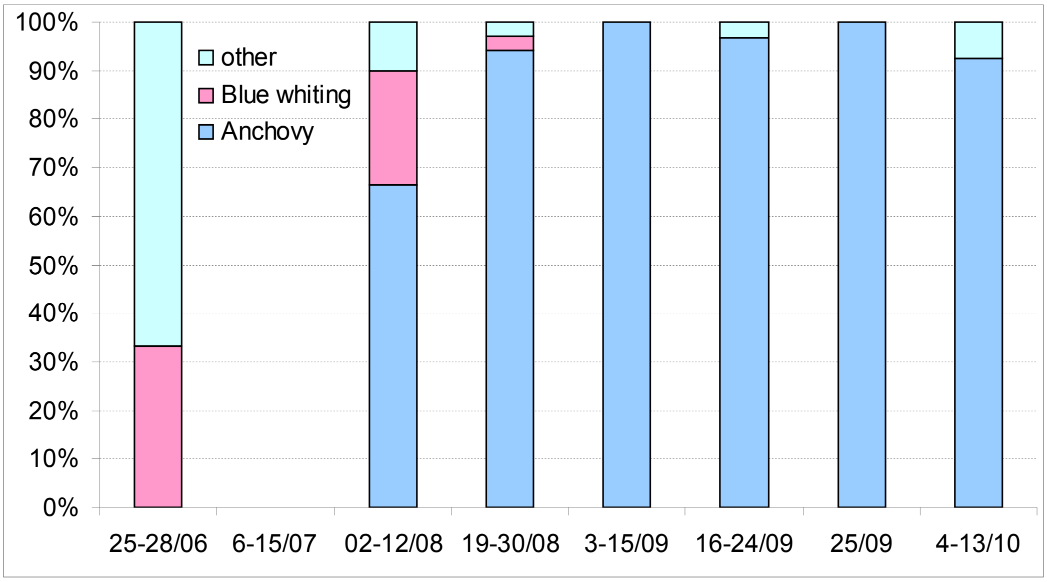


Figure 9: relative mean weight percentage of anchovy and blue whiting in the diet of bluefin present in the Bay of Biscay in 2010.

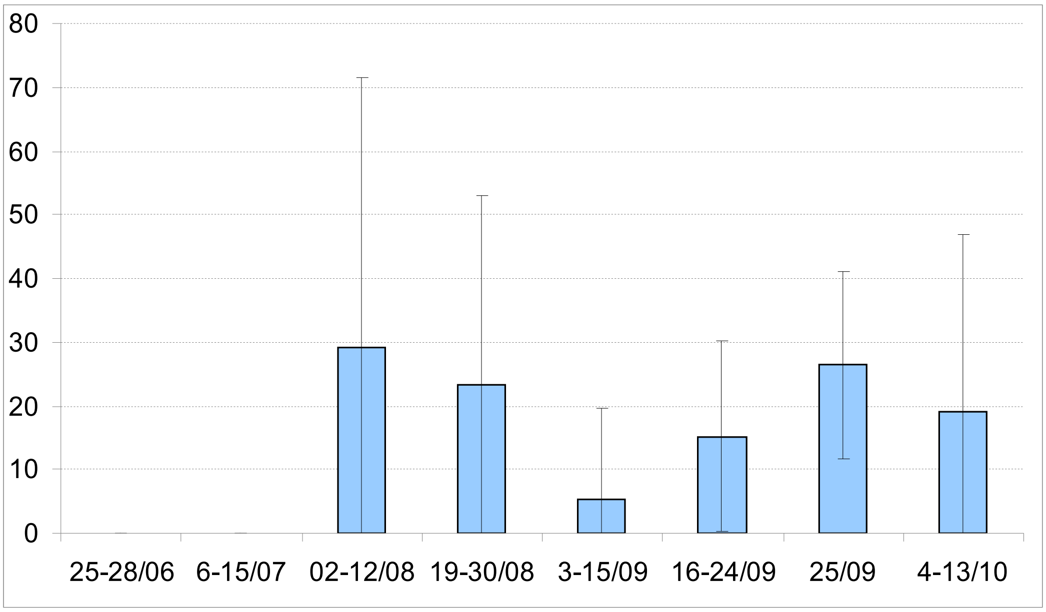


Figure 10: mean number (and standard deviation) of anchovy consumed by day by bluefin tuna caught in the Bay of Biscay in 2010.

4. Discussion

4.1. Seasonal patterns

The absence of anchovy in the diet of both tuna species until August in all sampled years is likely to be related to the life-cycle of anchovy. Anchovies usually remain over the continental shelf during larval stage until August, then as juveniles migrate over the continental slope and to the oceanic area in which they are fed upon by tunas.
Seasonal patterns also differ between the sampled years. These differences are probably related to variations in anchovy abundance, which was higher in 2005 than in 2006 and 2007 during the collapse period, and higher in 2010 than in 2009 during the recovery period.

4.2. Geographical patterns

The observed geographic variations in anchovy consumption by albacore are related to anchovy distribution area, which does not extend out of the Bay of Biscay. However, we can notice a broader distribution of anchovy in the Bay of Biscay during the recovery period than during the collapse period. During the collapse period anchovy was present only in the southeastern corner of the Bay of Biscay, which probably constitutes the core area of this species.

4.3. Anchovy sensivity to tuna predation

The absence of estimates of local tuna abundance does no allow any precise estimation of predation impacts on anchovy population. However, on a qualitative point of view, the restricted geographic distribution of anchovy during the collapse period suggests a lower exposure to albacore predation. On the other hand, the absence of albacore in the inner Bay of Biscay since 2008 tends to reduce predation impacts.

4.4 Tuna sensitivity to anchovy abundance

According to a previous study on the variations of albacore and bluefin fat content during summer in the Bay of Biscay (Goñi and Arrizabalaga, 2010), fat content of bluefin tuna usually increases from early August onwards, which coincides with the occurrence of anchovy in their diet. During the collapse period, in the sampling year with lowest anchovy abundance age-1 bluefin tunas did not display any increase in their fat content, which suggests a higher dependency of age-1 bluefin tuna to anchovy abundance the for older age-groups. This could have important implications in terms of growth and survival of bluefin tuna. However, the absence of fat content data for the recovery period does not allow any comparison or further interpretation.

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